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Final Report

A ROCKWELL HARDNESS TEST FOR PORTLAND CEMENT CONCRETE

TO: H. L. Michael, Director
Joint Highway Research Project

July 1, 1981

Project: C-36-65F

FROM: D. N. Winslow, Research Associate
Joint Highway Research Project

File: 5-15-6

Attached is the Final Report on the HPR Part II Study titled "Development of a Non-Destructive Test for Small Portland Cement Concrete Specimens". The Report is titled "A Rockwell Hardness Test for Portland Cement Concrete". It has been authored by the principal investigator, Professor D. N. Winslow.

The objective of the Study was accomplished. As the report title indicates a Rockwell Hardness Test was developed and evaluated. The test is non-destructive and provides an evaluation of the strength of portland cement mortars and concrete.

The Final Report is forwarded for review and acceptance by all sponsors as fulfilling the objectives of the study. With its approval and subsequent publication, the referenced HPR Study will be completed.

Respectfully submitted,

D. N. Winslow
Research Associate

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A ROCKWELL HARDNESS TEST FOR PORTLAND CEMENT CONCRETE

by

Douglas Winslow
Research Associate

Joint Highway Research Project

Project No.: C-36-65F

File No.: 5-15-6

Prepared as a part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data represented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Purdue University
West Lafayette, Indiana
1 July 1981

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-81/12		

4. Title and Subtitle	5. Report Date
A ROCKWELL HARDNESS TEST FOR PORTLAND CEMENT CONCRETE	July 1, 1981
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
D. N. Winslow	JHRP-81-12

9. Performing Organization Name and Address	10. Work Unit No.
Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907	11. Contract or Grant No. HPR-1(19) Part II
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Indiana Department of Highways State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration. From HPR-1(19) Part II Study titled "Development of a Non-Destructive Test for Small Portland Cement Concrete Specimens".

16. Abstract

The ASTM standard Superficial Rockwell hardness test using a 1/2 inch ball indenter and a 15 kgf Major Load (15Y test) has been adapted to perform non-destructive hardness tests on portland cement mortars and concrete. Correlations between the compressive strength of both materials and their hardnesses have been found. The correlation for normal concrete and 3" x 6" compression cylinders is:

15Y hardness = 73.5 x (log compressive strength in psi) - 187

and has a correlation coefficient of 88%. The test can be performed on samples as thin as 2 mm, on surfaces with a radius of curvature no less than 2 cm and as close to a sample edge as 1 mm. The test uses a standard Rockwell Superficial hardness test instrument but requires a tungsten carbide indenting ball and a sufficiently large sample support to hold the size sample that is being tested.

17. Key Words	18. Distribution Statement
Hardness, Rockwell Hardness, Strength, Mortar, Concrete, Non-destructive Testing	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The author wishes to thank Ziza Sabet for her patient and excellent technical assistance during the course of this research. Her efforts contributed greatly to the success of the project.

Financial assistance for this work was provided by the Indiana State Highway Commission and the Federal Highway Administration through the Joint Highway Research Project. The author is grateful for this support.

TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	v
HIGHLIGHT SUMMARY	vi
INTRODUCTION	1
EXPERIMENTAL PROCEDURES	4
Hardness Testing Instrument	4
Hardness Test Procedure	6
Mortar Testing	7
Special Effects of Sample on Measured Hardness	8
Concrete Testing	9
RESULTS OF MORTAR TESTS	12
Surface Roughness Effect	12
Hardness - Strength Correlation	13
Thickness Effect	14
Surface Curvature Effect	15
Proximity to Edge Effect	16
RESULTS OF CONCRETE TESTS	18
DISCUSSION	20
Moisture Content of Hardness Samples	20
Surface Roughness	20
Effects of Fine and Coarse Aggregate Type	22
Zone of Influence Below Indenter	23
Statistical Considerations	24
SUMMARY OF THE TEST METHOD	27
CONCLUSIONS	28
REFERENCES	29

LIST OF TABLES

Table		Page
1.	Concrete Mixture Proportions	10
2.	Surface Roughness vs. Hardness	12
3.	15Y Hardness-Strength Correlations for Mortar Cubes..	13
4.	7.5Y Hardness-Strength Correlations for Mortar Cubes.....	14

LIST OF FIGURES

Figure		Page
1.	Rockwell Hardness Tester Equipped to Test a Section of a Concrete Core.....	5
2.	Mortar Hardness vs. Specimen Thickness.....	15
3.	Mortar Hardness vs. Specimen Diameter.....	16
4.	Mortar Hardness vs. Proximity to Edge	17
5.	Concrete Hardness vs. Compressive Strength (for 3" x 6" cylinders).....	19

HIGHLIGHT SUMMARY

The ASTM standard Superficial Rockwell hardness test using a 1/2 inch ball indenter and a 15 kgf Major Load (15Y test) has been adapted to perform non-destructive hardness tests on portland cement mortars and concrete. Correlations between the compressive strength of both materials and their hardnesses have been found. The correlation for normal concrete and 3" x 6" compression cylinders is:

15Y hardness = 73.5 x (log compressive strength in psi) - 187

and has a correlation coefficent of 88%. The test can be performed on samples as thin as 2 mm, on surfaces with a radius of curvature no less than 2 cm and as close to a sample edge as 1 mm. The test uses a standard Rockwell Superficial hardness test instrument but requires a tungsten carbide indenting ball and a sufficiently large sample support to hold the size sample that is being tested.

INTRODUCTION

Various methods of non-destructively testing portland cement concrete have been in use for many years. These methods involve the measurement of some property of the concrete that is then used to infer the expected compressive strength. The great advantage of these tests is that the desired strength is obtained without the necessity of destroying the concrete. A secondary advantage is that typically, this class of tests, does not take long to perform.

The properties that are measured and correlated with strength fall into three main categories: the depth to which an indenter can be driven into the concrete, the amount of elastic rebound achieved by a hammer striking the concrete and the velocity of an elastic wave traveling through the concrete. All of these tests involve a comparatively large volume of concrete. Also, for the indentation and rebound tests the sample must be well anchored so that it cannot move and effect the results.

It is desirable to have a non-destructive test that involves a much smaller volume of concrete and that does not require the sample to be so securely anchored. Such a test could be used to study local variations in strength within the concrete and, it could be applied to small samples such as surface spalls and small cores. A test of this nature would be useful both in research and in the investigation of concrete that was experiencing distress. It could, for example,

be used to measure changes in strength of a pavement slab from top to bottom and to investigate the effects on strength of bleeding, vibration and curing. It could also be used to determine the extent to which a deleterious reaction had invaded a piece of concrete and damaged it. And, it could be applied to polished sections of concrete to verify point-to-point differences that appear to exist upon visual examination.

The research investigation reported here is concerned with the development of such a non-destructive test method. The test method is, fundamentally, the standard Rockwell hardness test. In this work it has been adapted to small samples of portland cement concrete and the necessary correlations between measured hardness and compressive strength have been developed.

A considerable amount of hardness testing has already been performed on hydrated portland cement pastes. (1,2,3). These tests were performed with one of two standard types of micro-hardness testers. In addition to portland cement, a variety of other cementitious systems were examined. The compressive strength, modulus of elasticity and porosity of the samples were also measured. In all this work excellent correlations were established between the three physical properties of the pastes and their micro-hardness. The general conclusion of this work was that micro-hardness testing of cement pastes was a sensitive test that provided useful information about the mechanical properties of the material.

Micro-hardness testing involves the use of a small pyramid-shaped diamond indenter that is forced into the material with a comparatively small load. The size of the resulting indentation is taken as a

measure of the hardness of the material. If micro-hardness testing is to give useful results it is important that the material under test be homogeneous on a size scale commensurate with the area that is sampled by the indenter. That is, the average properties of the material over a distance approximating the size of the indentation must not vary greatly.

The aim of the current research was to test concrete, not cement paste. Concrete is much less homogeneous than paste, and, thus, requires a hardness test with a larger indenter. On the other hand, current "macro-hardness" tests, such as the Windsor Probe, have much too large an indenter and indenting force to be suitable for testing small samples and examining comparatively local variations in properties. For this purpose a test with an intermediate size indenter is required.

Such intermediate sized hardness tests are already used on a number of materials. The Rockwell series of tests has the widest range of indenting forces and indenter sizes. The problem, then, is to find a specific Rockwell test that possesses a suitable combination of indenter size and force to give useful results with concrete samples.

The general plan of the research work was to first investigate hardness measurements on mortar samples. These experiments were used to establish the best method of determining the Rockwell hardness of a mortar. They also served to examine limitations, i.e. sample curvature, to the method. The work was then extended to concrete samples and, a hardness-strength correlation was established.

EXPERIMENTAL PROCEDURES

Hardness Testing Instrument

All of the hardness tests that were made in the course of this research were made on a standard, commercially available, Rockwell hardness tester (Wilson Instrument Co. Model TY). This instrument is capable of performing both the regular and the superficial Rockwell hardness tests. However, only the superficial tests were found to be applicable to mortar and concrete and, a test instrument capable of performing only the superficial tests would be adequate.

The standard indenting balls that are normally used are made of hardened steel. These would be damaged by some types of aggregate, quartz in particular, that are found in mortar and concrete. Hence, the instrument was equipped with a tunsten-carbide indenting ball. This is also commercially available (Wilson Instrument Co. Part No. 1020-00464), and is harder than naturally occurring aggregates.

It is crucial that, during a hardness test, the sample rests upon a firm base and is completely immobile. The standard hardness test instruments have comparatively small sample supports. These are much too small to support portions of concrete cylinders or cores. Thus, an especially large sample platform was custom fabricated. This platform rests on the central, threaded support of the instrument as do the standard platforms. Its sample support surface is a rectangle approximately 10 inches by 18 inches. The standard Rockwell tester

with the special support table is shown in Figure 1.

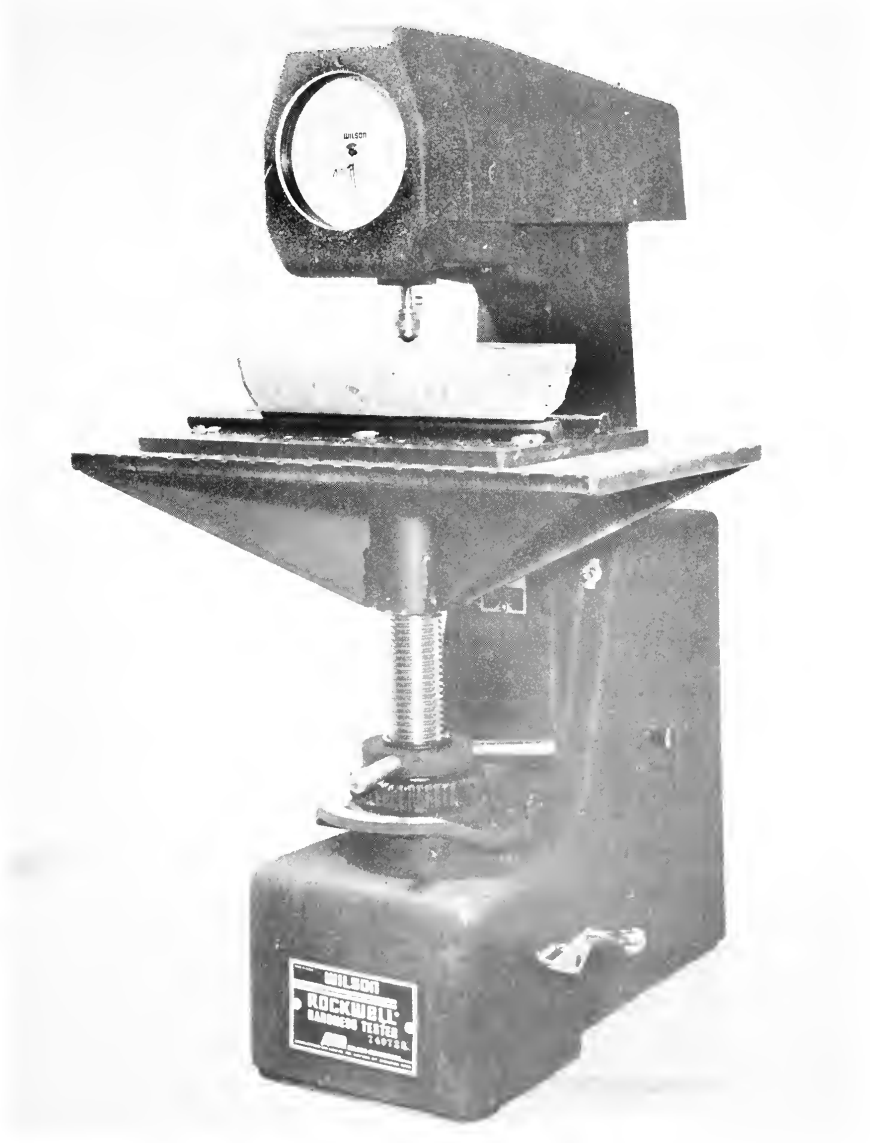

Figure 1. Rockwell Hardness Tester Equipped to Test a Section of a Concrete Core.

Hardness Test Procedure

All of the Rockwell hardness tests in this research were conducted in accordance with ASTM Test Method E-18 (4). In this method, the indenter is forced slightly into the surface of the sample with a small force called the Minor Load (3 Kgf). A dial on the instrument that can sense the depth of penetration of the indenting ball into the sample is then set to zero. A second, greater force is then applied to the indenter. This force is called the Major Load and, for the superficial tests, can be 15, 30 or 45 Kgf. After a period of 5 to 10 seconds the Major Load is removed. The depth of the permanent dent made by the Major Load is sensed by the instrument's dial. ASTM assigns a letter code to the various indenters used in the superficial test series. Each letter is preceeded by a number giving the Major Load. Thus a test designated as 15Y refers to a 1/2" diameter spherical indenter and a 15 Kgf Major Load. This particular test was found to be the most applicable in this research.

The Rockwell superficial hardness is defined as the depth of penetration caused by the Major Load, measured in micrometers, subtracted from 100 and is read directly from the instrument's dial. The hardness is defined in this way so that a hard material, that would have a small penetration, will have a large hardness number and vice versa. If the penetration depth exceeds 100 μm then the Major Load must be reduced.

In the usual Rockwell test the sample is positioned beneath the indenter using the unaided vision of the operator. In this research

the intent was to direct the indenter at mortar regions and away from pieces of coarse aggregate. The use of an illuminating magnifier was found to aid in this. When the sample was being positioned under the indenter for a test it was observed through a 3X circular magnifier fitted with a surrounding florescent light. This refinement is not necessary to the test method; however, it was found that it made the testing easier.

Mortar Testing

In the initial phase of this research samples of mortar were prepared and tested. The mixing and casting procedures were those perscribed in ASTM Test Method C-109 (5). An ASTM Type I portland cement was used throughout. Three different fine aggregates were used but, they were always combined with the cement in the weight ratio used in C-109. Mortars were prepared at several, and non-ASTM standard, water cement ratios. The ratios that were used were: 0.4, 0.5 and 0.6. Nine cubes were cast from any one batch and, after 24 hours, they were demolded and placed under lime saturated water to hydrate until they were tested.

Five to seven separate batches of mortar were mixed for each combination of fine aggregate type and water:cement ratio. These were allowed to hydrate for periods ranging from 1 to 60 days and then removed for testing.

The nine cubes from any single batch were removed together. Six of these were tested for compressive strength as per C-109 and the average of these six results was considered the compressive strength of that particular age and type of mortar. The other three

cubes were sawed in half along a plane that had been vertical when the cubes were originally cast in their molds. Hardness tests were always performed on the mortar when it was saturated with water. Ten separate hardness tests were then conducted on the sawn face of one half of each cube. The tests were performed on these sawn surfaces to avoid any anomalies that might be present at the cube-mold interface. The ten tests on any one surface were spread equally across its area. The average of the thirty hardness test results was considered to be the Rockwell hardness of that particular age and type of mortar.

All of the mortars were mixed with fine aggregate having the particle size distribution specified in C-109. In one set of mortars the fine aggregate was composed completely of quartz. In another it was limestone. In a third it was a locally available river sand whose principle constituents were quartz, limestone, dolomite, sandstone and chert. Whichever fine aggregate was being used, all three water:cement ratios were mixed and specimens were tested over the previously mentioned range of ages.

Special Effects of Sample on Measured Hardness

The effect of the roughness of the sawn surface upon the measured Rockwell hardness was investigated. A set of ostensibly identical mortar cubes was prepared and sawed. One cube's surfaces were left in the as-sawed condition. Other surfaces were polished with abrasive grits to varying degrees of smoothness. The grits that were used as the final polishing materials for the series of samples were: #60, #100, #180, #240, and #600. Hardness tests were then performed on each class of surface.

In a Rockwell hardness test it is possible that the much harder sample support may influence the measured hardness if the sample is too thin. A series of slices of similar mortar were prepared to investigate this. Slices were sawn to have thicknesses ranging from 2 mm to 20 mm. Hardness tests were then performed on each slice.

The curved surface of a cylindrical sample can also effect the measured hardness. This is because the material being tested does not surround the indenter equally in all directions. To investigate this effect a series of cylindrical mortar specimens were prepared with diameters from 10 mm up to 70 mm and hardness tests were performed on the curved surfaces of them.

Finally, a series of experiments was conducted to determine how closely a hardness test could be conducted to the edge of a sample.

Concrete Testing

Following the mortar testing phase of the research concrete specimens were prepared and tested. The proportions of the constituents of the concrete mixtures are given in Table 1.

Concrete using these proportions was prepared at three different water:cement ratios: 0.4, 0.5 and 0.6. The concrete was cast in standard 3" x 6" cylinder molds. The cylinders were demolded after 24 hours and placed in lime saturated water to hydrate for various periods before testing. A single mix at one water:cement ratio was sufficient to make 54 cylinders. Nine cylinders from a batch were tested at each of 6 ages ranging from 1 day to 28 days.

Table 1. Concrete Mixture Proportions

Constituent	Mass (Kg)
Type I Portland Cement	15.5
Fine Aggregate (FM = 2.9)	30.9
Coarse Aggregate	
3/4" - 1/2"	11.8
1/2" - 3/8"	11.8
3/8" - 1/4"	23.6

When the desired age was reached six of the nine cylinders were capped and broken in compression. The average strength of these six was taken to be the compressive strength of that particular batch at that particular age.

The other 3 cylinders were used for hardness tests. A flat surface was ground on each cylinder parallel to its long axis. This surface, approximately 1 inch wide and extending the full 6 inch length of the cylinder, was used for testing to avoid any anomalies at the concrete-mold interface. All concrete samples were tested while saturated with water. Ten hardness tests, equally spaced along the surface were performed on each of the three cylinders and the average of these 30 results was considered to be the hardness of the concrete from that batch at that time.

Two different fine and coarse aggregates were used in the various batches of concrete. The fine aggregate was either the limestone or the local river sand previously used in the mortar studies. Whichever fine aggregate was being used, it was always combined to yield a material with the same particle size distribution and having a Fineness Modulus of 2.9. The coarse aggregate was either crushed limestone or gravel. In either case, the coarse aggregate was always proportioned as given in Table 1. Batches of concrete were mixed using all possible combinations of these fine and coarse aggregates. In addition, one air entrained batch using the river sand and gravel was prepared.

RESULTS OF MORTAR TESTS

Surface Roughness Effect

The effect, if any, of surface roughness on the measured hardness was investigated in an early series of experiments. The results of a typical series of tests are given in Table 2.

Table 2. Surface Roughness vs. Hardness

Final Surface Treatment	As-sawed	#60 grit	#100 grit	#180 grit	#240 grit	#600 grit
Ave. Hardness No.	45	48	49	51	52	49
Coefficient of Variation of Hardness Measurements	41%	26%	23%	23%	26%	21%

With the possible exception of the as-sawed surface, the average hardnesses are virtually the same. The as-sawed surface demonstrated a much greater scatter between individual test results. In view of these results a relatively modest polishing with a #240 grit material was adopted as the standard surface pre-treatment for all subsequent mortar and concrete testing.

Hardness - Strength Correlation

Mortars were mixed and tested with three different fine aggregates. In each case, a correlation was found between the mortar cube compressive strength, in pounds per square inch, and the Rockwell 15Y hardness. Several possible functional relationships were tried for these correlations and the best one was always found to be between the hardness value as a linear term and the compressive strength as a logarithmic term. The correlation functions for the mortars are given in Table 3 along with their correlation coefficients. These correlations are known to be applicable for compressive strengths ranging from 2000 psi to 7000 psi. In addition, all of the mortar results were grouped together and a correlation, irrespective of fine aggregate type, was found. This is also given in Table 3.

Table 3. 15Y Hardness-Strength Correlations for Mortar Cubes

General Correlation

Rockwell 15Y Hardness = A + B x log(Compressive Strength in psi)

Fine Aggregate	Value of A	Value of B	Correlation Coefficient
C-109 Quartz Sand	-205	+79.5	96%
Limestone fines	-178	+68.4	98%
River sand	-153	+62.2	96%
All mortars	-152	+62.4	87%

Some of the very weakest mortars allowed the hardness tester to go off-scale (too deep an indentation) with the 15 Kgf Major Load. A special counter weight was made for the instrument that produced a Major Load of 7.5 Kgf and this test, called a 7.5Y, was performed on these weak mortars. The resulting correlations for this are given in Table 4. They are known to be applicable for compressive strengths ranging from 750 psi to 4000 psi.

Table 4. 7.5Y Hardness-Strength Correlations for Mortar Cubes

General Correlation
Rockwell 7.5Y Hardness = A + B x log(Compressive Strength in psi)

Fine Aggregate	Value of A	Value of B	Correlation Coefficient
C-109 Quartz Sand	-177	+76.8	96%
Limestone fines	-22.5	+30.4	98%
River sand	-41.4	+36.0	96%
All mortars	-73.2	+44.9	91%

Thickness Effect

The hardnesses of mortar samples of varying thicknesses were determined to investigate the possible influence of the tester's support on the measured value. The results of these tests, for mortars of two maturities are shown in Figure 2.

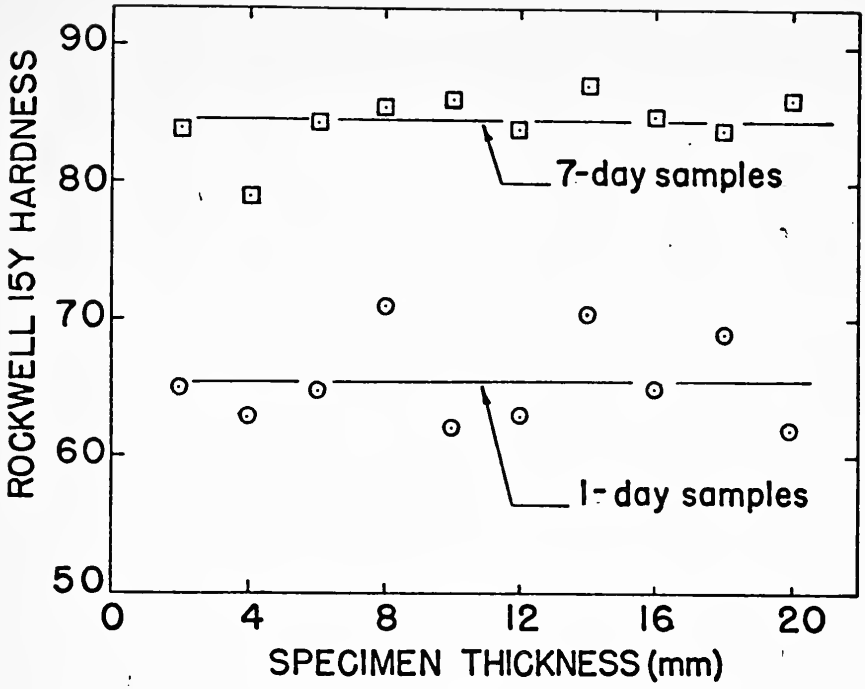

Figure 2. Mortar Hardness vs. Specimen Thickness

Surface Curvature Effect

The hardnesses of cylindrical mortar samples of varying diameters were measured to assess the effect of surface curvature upon the measured values. The results, again for two maturities, are shown in Figure 3.

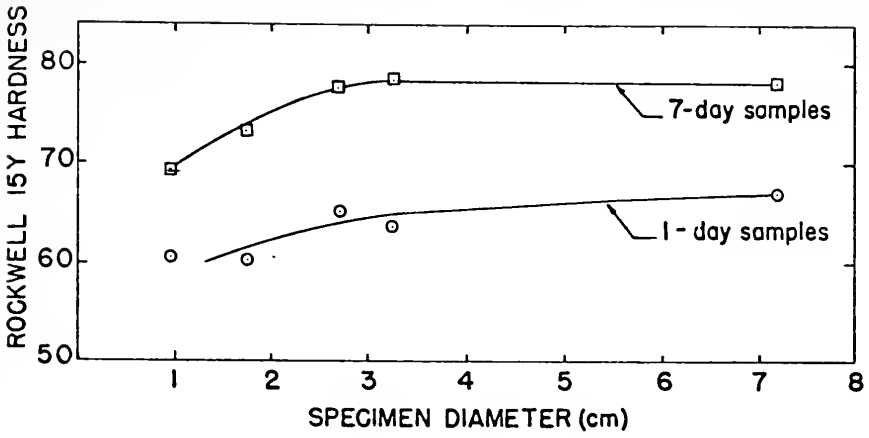

Figure 3. Mortar Hardness vs. Specimen Diameter

Proximity to Edge Effect

The hardness of a mortar cube was measured as a function of how close to the cube's edge the indentation was made. This was done for mortars of two ages and the results are shown in Figure 4.

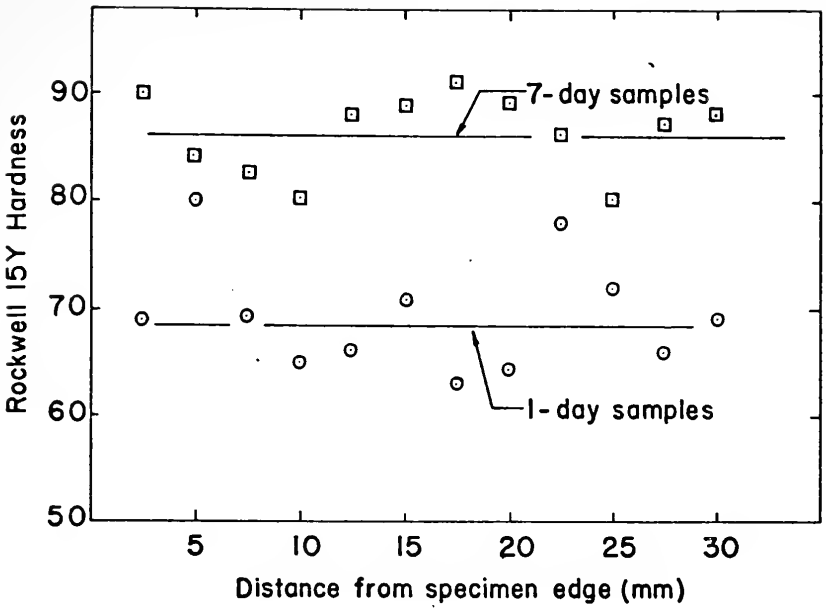

Figure 4. Mortar Hardness vs. Proximity to Edge

RESULTS OF CONCRETE TESTS

Concrete cylinders were made using various combinations of fine and coarse aggregate types. For the concrete, as distinct from the mortar cubes, no significantly different correlations were found between hardness and aggregate types. Various functional forms of the correlation were examined and the best was, again, found to be a semi-logarithmic one.

The correlation equation for all concretes was found to be:

15Y Hardness = 73.5 x (log compressive strength in psi) - 187

with a correlation coefficient of 89%. In this correlation the compressive strength is that for 3" x 6" concrete cylinders. The hardness was measured on a surface that had been polished with #240 grit and, that was tested in the saturated, surface-dry condition. This correlation, along with discrete data points that were determined, is shown in Figure 5.

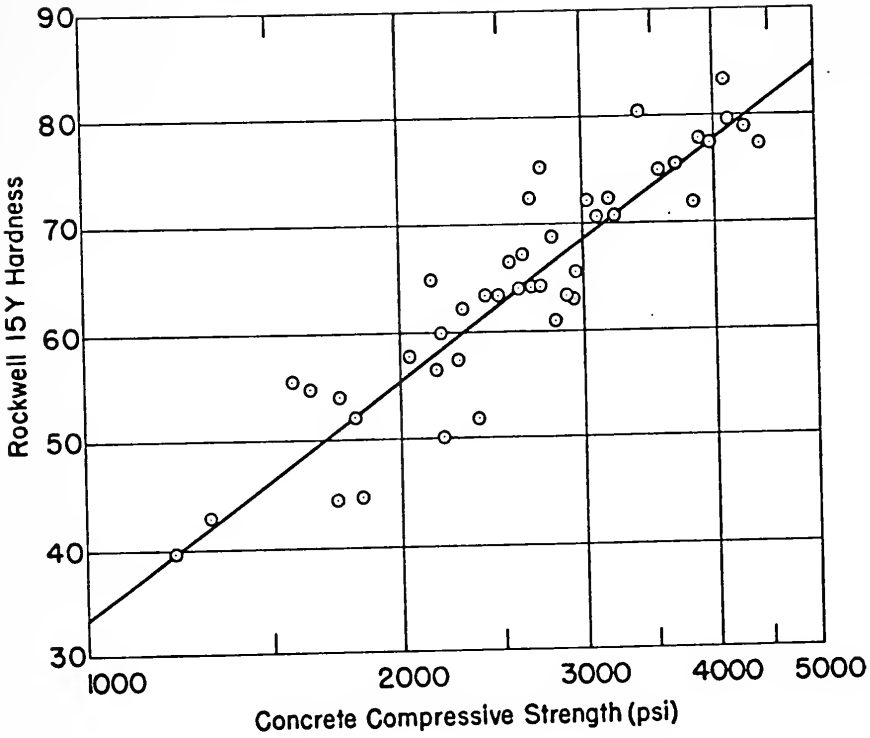

Figure 5. Concrete Hardness vs. Compressive Strength (for 3" x 6" cylinders)

DISCUSSION

Moisture Content of Hardness Samples

Earlier work on the hardness of portland cement paste (1) showed that, other factors being held constant, the measured hardness of the material was a function of its moisture content. Thus, in the development of a strength-hardness correlation, all samples must be tested at a single moisture content. The only two moisture contents that can be achieved comparatively easily are the saturated and the oven dry states. In this work the saturated state was selected. This was done to avoid the necessity for drying specimens that might, for other experiments, be required to be in the saturated condition.

Surface Roughness

The data presented in Table 2 indicate that there is no significant effect of surface roughness upon measured hardness. Intuitively one might expect a rougher surface to have a lower hardness due to the crushing of 'peaks' of material below the indenter. The data also show that there is an effect upon the scatter of individual measurements about their average value. Although these phenomina were not further studied the following may be their explanation.

The Rockwell hardness tester measures the depth of penetration of an indenter. If this indenter is brought to bear on a high spot in the surface then the material will have less surrounding support

and should permit a greater indentation and a consequently lower hardness to be measured. However, the test is always preceeded by the application of a Minor Load of 3 Kgf and the hardness measurement is based solely on the additional penetration resulting from the application of the Major Load. The diamond saw used to prepare the roughest surface examined in this study left behind a moderately smooth surface, although, certainly not a polished one. It may be that, for surfaces as smooth or smoother than the as-sawed one, the Minor Load is sufficient to produce the crushing of local high spots. Thus, the hardness tests may be performed on surfaces that have been, in fact, equally smoothed by the Minor Load. However, potential users of this testing procedure are cautioned not to consider that the method will prove indifferent to truly rough surfaces. At some state of roughness the Minor Load will, presumably, be unable to completely crush the high spots. The test results will, then, show a dependence on roughness.

The Coefficient of Variation was found to be appreciably larger for tests conducted on the as-sawed surface than for surfaces that were polished. It is believed that this is because it is harder to see mortar regions that are comparatively free of either the larger aggregate sizes or entrapped air bubbles. Thus, the chances of recording the hardness of an aggregate piece or an entrapped air bubble are raised and, although the average of a number of tests is unaffected, the variation in individual results is increased. In order to reduce this scatter and to also keep the polishing to a minimum the standard surface preparation with a #240 grit grinding powder was adopted.

Effects of Fine and Coarse Aggregate Type

In the test series using mortar cubes, a small effect of fine aggregate type upon measured hardness was observed. Generally, for mortars of the same compressive strength, a harder fine aggregate resulted in a greater mortar hardness. This is a logical finding that one would expect.

The result of this finding is that, for maximum accuracy, a particular correlation with strength should be employed for each fine aggregate type. However, the correlation that grouped all mortars together, regardless of fine aggregate, still has a correlation coefficient of 87% and, for much testing, this may well be sufficiently accurate.

The concrete samples showed no significant dependence of hardness upon fine aggregate type. This is, perhaps, because the concrete results generally had more scatter and, the small difference observed in the mortar tests is lost in the scatter of the data.

Further, the concrete's hardness-strength correlation was unaffected by the type of coarse aggregate. This is not surprising since the hardness tests were performed on and the compressive strength is largely controlled by the mortar between the coarse aggregate pieces.

A caution must be added to all of the above findings on aggregate type. Only comparatively common and widely used, 'normal', aggregates were examined. It is entirely possible that either exceedingly hard or soft aggregates might result in a significantly different strength-hardness correlation. This may be particularly true in the case of

light-weight concretes. Special effects such as this were not investigated in this study.

Zone of Influence Below Indenter

Various theoretical analyses have attempted to define the volume of material, below a loaded region on its surface, that effects the deflections from that load. None of these analyses is exact for a real material such as concrete. However, they all indicate that, under a small, loaded area, there is a rounded bulb of influence that is several times as wide as the width of the loaded region and, perhaps twice that in depth.

In the hardness tests, the load is applied to a dent in the surface that is a segment of a sphere. Typically, this dent has a diameter, at the tested surface, of about a millimeter and a maximum depth of a few hundreths of a millimeter.

In this work, no attempt was made to carefully define the zone of influence under such a region. However, the experiments on sample thickness and proximity to sample edge do shed some light on the question. They show that hardness values are not significantly effected when the sample is as thin as 2 mm and when the test is performed as close as 1 mm to a sample's edge.

These results place some rough limits on the maximum size of the zone of influence. It is apparently no wider than about twice the width of the indentation and of a depth of about twice the indentation width. While these findings are somewhat smaller than some analytical predictions, they are, still, about the right order of magnitude.

They also allow a rough estimate of the volume of mortar that is being tested in any one indentation. If one assumes a roughly spherical zone of influence below the test then a maximum volume of approximately 5 mm^3 of mortar is contributing to any single test result.

Statistical Considerations

Hardness values obtained on ostensibly similar concrete inherently show some scatter. This is because of the nature of the material being tested and because of the small volume of material that influences any one test. A single test can be done relatively rapidly and, typically, a number of tests will be performed and their average used as the hardness value of the material. The question then arises: how many tests should be conducted to obtain a good average?

No simple or exact answer can be given for this question. In many cases the number of tests may be limited by sample size or geometry and that number will have to suffice. But, in other cases, many tests will be possible. One way to decide how many tests should be conducted is to consider how well the average of a certain number of tests predicts the actually measured compressive strength.

Toward this end a series of tests were conducted in which 90 hardness values were obtained on concrete cylinders ranging in age from 1 day to 60 days. From these values three different average hardnesses were extracted for each age concrete. The first average was based upon the first 10 values obtained in each testing sequence. This would be the average if only 10 tests had actually been made.

A second average was based on the first 30 values in each sequence and a third average was based on all 90 values from each age concrete. These averages were then, separately, used to predict the concrete's compressive strength using the hardness-strength correlation and, this prediction was compared to the average compressive strength measured on six companion concrete cylinders. The results are given in Table 5. The errors given in Table 5 are the averages of the absolute values of the errors for individual concrete types. In individual cases the errors were sometimes positive and sometimes negative with no pattern being discernable as regards the signs of the errors.

Table 5. Number of Replicate Tests and Relative Accuracy of Test Prediction.

Number of replicate tests	10	30	90
Avg. % error in predicting strength for all cylinders	16.5%	12.3%	7.6%
Approx. time required to perform all tests	4 min.	10 min.	30 min.

The obvious conclusion of Table 5 is that the chances of accurately predicting a compressive strength increase with the number of tests performed. However, so too does the time required for the experiment. Individual experimenters will have to decide what tradeoff they wish to make between accuracy and efficiency. In making this decision it should be kept in mind that any number of tests will still sample a much smaller volume of material than a compression

test and, that hardness testing should not be considered a substitute for a compression test when the latter is possible.

Another statistical consideration is the spread of individual data points about their mean value. Because the means of various tests will be different it is best to examine the coefficients of variation of sets of hardness values. Although no special study of this question was undertaken, a general trend was observable. The weaker concretes had a larger coefficient of variation than the more mature ones. Typical values of the coefficient of variation might be 20% for samples with a compressive strength of 1500 psi, 10% for 2500 psi concrete and 5% for 4000 psi concrete. Above 4000 psi there is little, if any, improvement in the variation. The cause of this trend was not examined but it may arise from an inhomogeneity in the degree of hydration of young samples. At early ages some regions may be more completely hydrated, and harder, than others while at later ages the less well hydrated regions may have 'caught up' with a consequent reduction in the data spread.

SUMMARY OF THE TEST METHOD

1. The test instrument is a standard Rockwell Superficial hardness tester conforming to and used in accordance with ASTM Standard E-18.
2. The instrument is equipped with a 1/2" diameter tungsten carbide indenting ball and applies a Major Load of 15 Kgf., i.e. a standard 15Y test. The instrument must also be capable of rigidly supporting the size specimen to be tested.
3. The concrete sample should have either a plane surface or one with a radius of curvature in excess of 2 cm.
4. The surface should be polished with a #240 grit polishing powder. This polishing should be continued until the naked eye can clearly distinguish between regions of mortar and coarse aggregate.
5. The concrete shall be tested in the saturated, surface dry condition.
6. The indenter shall be directed toward mortar regions upon which the hardness test shall be conducted. Tests shall not be done on coarse aggregate pieces or regions that obviously contain large, entrapped air pockets. Additional light and/or modest magnification may be used to aid the operator in positioning the sample under the indenter.

CONCLUSIONS

1. The ASTM Standard 15Y Rockwell Superficial Hardness Test can be used on portland cement mortar and concrete. When used on concrete the hardness of the mortar regions is measured.
2. The measured hardness is not a function of surface roughness as long as the surface is reasonably smooth.
3. The hardness can be measured as close as 1 mm to a sample's edge, on samples as thin as 2 mm and, on surfaces that have a radius of curvature in excess of 2 cm.
4. For normal concrete mixes, the best correlation between the compressive strength of 3" x 6" cylinders and the 15Y hardness value is:

   15Y Hardness = 73.5 x (log compressive strength in psi) - 187

   This relation has a correlation coefficient of 89% and applies to concrete that is tested in the saturated, surface-dry state.
5. The correlation is known to apply to concretes with compressive strengths ranging from 1000 psi to 5000 psi.

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